3/25/93

Program TRENDS: User's Guide

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ABSTRACT

A microcomputer-based program named TRENDS implements the power analysis for detecting trends in abundance using linear regression described in Gerrodette, Ecology 68: 1364-1372 (1987) and Gerrodette, Ecology 72: 1889-1892 (1991). TRENDS is simple to use and allows easy calculation of statistical power, number of sampling occasions, sample precision, and detectable rate of change in abundance. This manual describes program structure, outlines numerical techniques, lists error messages, and gives several detailed examples of the program's use.

INTRODUCTION

Linear regression is often used to assess trends in some quantity of interest to wildlife biologists, such as population size, community diversity, or birth rate. For ease of explanation, change in population size is used as an example in this guide, but the results apply equally well to any linear regression problem. Gerrodette (1987, 1991) described an approach for conducting a power analysis of linear regression. The numerical solution of the equations given in those papers, however, is not trivial, particularly if the calculations are based on the t distribution. Program TRENDS is a user-friendly program to carry out those calculations. The program structure makes it easy to see the effect of altering various parameters on the value of the computed parameter of interest. TRENDS was developed to aid in designing field studies, but it could also be useful to teachers and students in a course on field methods or experimental design.

The approach implemented here assumes that we plan to make a series of independent estimates of abundance of some quantity of interest, at equal intervals of an independent variable, such as time or distance, and to follow the same methods of estimation on each sampling occasion. A trend is evaluated by regressing the estimates of abundance against time or distance and testing the slope of the regression line against a null hypothesis of zero slope. Such an experimental design will usually satisfy the assumptions of linear regression closely, with two important exceptions:

(1) If the nature of the process of change is multiplicative rather than additive, points will not be linear but will lie along an exponentially increasing or decreasing curve. This is a common situation for many practical problems of interest. A logarithmic transformation of the estimates will make them linear, and such a transformation usually has the additional positive effect of making the variances more nearly equal. Program TRENDS allows the user to choose between linear and exponential models of change.

(2) Even if equal effort and identical methods are used on each sampling occasion, the variances of the estimates will in general not be equal, as required by linear regression, but will be some function of abundance A. The situations treated here, which correspond to common methods of estimating population size, let the variance be proportional to A, A^2, or A^3 (Gerrodette 1987). In program TRENDS this is implemented by having the user choose among 3 patterns of change of coefficient of variation (CV=standard error/mean) with abundance: CV proportional to A^{-2}, CV constant with A, or CV proportional to A^2.

Gerrodette (1987, 1991) summarized the problem in 5 parameters: n, the number of sampling occasions; r, the rate of change in abundance that occurs between each sampling occasion; CV1, the coefficient of variation of the first estimate of abundance in the series; α, the significance level (probability of Type 1 error); and the statistical power ($1 - \beta$, where β is the probability of Type 2 error). The value of any parameter can be estimated if the other 4 are specified. The parameter of interest depends on the application.

The relations among these parameters are affected by a number of factors: (1) whether change is linear or exponential; (2) whether change is positive or negative; (3) whether the statistical test is 1- or 2-sided; (4) how the precision of the estimates depends on abundance; and (5) whether the standard normal (z) or Student's (t) distribution is used in the calculations.

More general approaches along the lines suggested in section (3) of Gerrodette (1991) are not implemented at this time. Future additions could allow sampling at unequal intervals, arbitrary patterns of variance, detection of nonlinear patterns, and correlation among estimates.

PROGRAM STRUCTURE

Program TRENDS is written in Microsoft FORTRAN 77 and the executable file will run on an IBM-compatible microcomputer. The main driver is an I/O interface that calls subroutine TREND, which carries out the calculations. Subroutine TREND, together with its supporting subroutines and functions, could be used in another user-written main program, if desired. TREND requires 2 specific external functions (FXL and FXE), 2 subprograms to compute the z and noncentral t cumulative distribution functions (CUMPR and PRNCT), and 2 subprograms to compute the inverses of those distribution functions (ZINV and TINV). Users could substitute their own routines for the latter 4 if desired.

The basic equations to be solved are

$$1-\beta=\Phi\left(z_{\alpha}-\frac{b}{\sigma_b}\right)$$

for a decreasing trend (b < 0),

$$1-\beta=\Phi\left(\frac{b}{\sigma_b}-z_{1-\alpha}\right)$$

for an increasing trend (b > 0), and

$$1-\beta=\Phi\left(z_{\alpha/2}-\frac{b}{\sigma_b}\right)+\Phi\left(\frac{b}{\sigma_b}-z_{1-\alpha/2}\right)$$

for a trend in either direction. If the z distribution is used, as above, Φ is the distribution function for the standard normal distribution. If the t distribution is used, replace z_α by $t_{\alpha,n-2}$ in the equations above, and let Φ be the distribution function for the noncentral t distribution. b is the expected value of the true slope of the regression line and σ_b its standard deviation; both are functions of r, n, and CV1. The exact expressions for b and σ_b as functions of r, n, and CV1 depend on the model of change (linear or exponential) and the pattern of change of CV with abundance, and are complicated (Link and Hatfield 1990). However, approximations given in Gerrodette (1987) are satisfactory for most cases and are used here. Roots are located with a tolerance of 0.001 using Brent's method (Press et al., 1989), slightly modified as ZBRENT. Initial root bracketing is accomplished with ZBRAC, another routine slightly modified from Press et al. (1989).

Program TRENDS accepts input either interactively or from an input file named TRENDS.INP. As values are given interactively, an input file is created so that runs can be repeated, or single values can be changed easily. Before computations are started, the program displays the input values and gives the user the opportunity to change any of them. Output is displayed on the screen and also saved in a file named TRENDS.OUT.

EXAMPLES

Sea otter

The sea otter example is described on p. 1368-69 of the 1987 paper. In an unpublished USFWS report, J.A. Estes reported the results of 7 replicate aerial strip transects for sea otters as: 582, 456, 415, 560, 519, 545, 611. The mean of these counts is 527, the sample standard deviation 69.7, and the coefficient of variation 0.13. Note that although the exponential model is used below, the CV is computed on untransformed counts.

This first example shows user input and program output in detail. User input, shown in bold lettering, is case insensitive.

```
TRENDS                       [Header appears]

One of the following parameters can be computed:

 (1)  number of samples (n)
 (2)  rate of change (+/- r)
 (3)  initial coeff. of variation (CV1)
 (4)  significance level (alpha)
 (5)  power (1-beta)

Enter value for index of parameter to be computed: 5

                        [Power is selected, so program
                         now prompts for other values]

Enter value for number of samples (n)           : 5

Enter value for rate of change (+/- r)          : .1

Enter value for initial coeff. of variation (CV1): .13

Enter value for significance level (alpha)      : .05

Enter value for 1- or 2-tailed test             : 2

Enter value for model (1=linear, 2=exponential)  : 2
```

```
   1=CV proportional to 1/sqrt(A)
   2=CV constant with A
   3=CV proportional to sqrt(A)

Enter value for pattern of CV with abundance A   : 1

   1=use z distribution (variance assumed known)
   2=use t distribution (variance est. from residuals)

Enter value for distribution index (1=z, 2=t)    : 1

                        [Input is complete; program displays
                         input values and prompts for change]

You have specified the following input values:

(1)  5                  number of samples (n)
(2)    .100                            rate  of  change  (+/-  r)
(3)  .130               initial coeff. of variation (CV1)
(4)  .050               significance level (alpha)
(5)  (to be computed)   power (1-beta)
(6)  2                  1- or 2-tailed test
(7)  2                  model (1=linear, 2=exponential)
(8)  1                  pattern of CV with abundance A
(9)  1                  distribution index (1=z, 2=t)


To proceed with these values, press ENTER;
to change one of them, enter the line number:  <ENTER>



*** PROGRAM TRENDS OUTPUT ***

Model of change: EXPONENTIAL
Pattern of variance: CV PROPORTIONAL TO 1/SQRT(A)
Calculation based on Z distribution
Alpha =       .050 (2-tailed)
Rate  =       .100
CV    =       .130
Sample size =    5

Given these parameters, power is estimated to be   .72



Do you wish to try another calculation? (Y/N)  y

                        [We'll try another combination]

You have specified the following input values:
```

```
(1)  5                  number of samples (n)
(2)  .100               rate of change (+/- r)
(3)  .130               initial coeff. of variation (CV1)
(4)  .050               significance level (alpha)
(5)  (to be computed)   power (1-beta)
(6)  2                  1- or 2-tailed test
(7)  2                  model (1=linear, 2=exponential)
(8)  1                  pattern of CV with abundance A
(9)  1                  distribution index (1=z, 2=t)


To proceed with these values, press ENTER;
to change one of them, enter the line number:  2

                        [We ask to modify the rate of change]

Enter value for rate of change (+/- r)          : -.1

                        [The rate is changed to a 10% decline]

You have specified the following input values:

(1)  5                  number of samples (n)
(2)  -.100                             rate  of  change  (+/-  r)
(3)  .130               initial coeff. of variation (CV1)
(4)  .050               significance level (alpha)
(5)  (to be computed)   power (1-beta)
(6) -2                  1- or 2-tailed test
(7)  2                  model (1=linear, 2=exponential)
(8)  1                  pattern of CV with abundance A
(9)  1                  distribution index (1=z, 2=t)


To proceed with these values, press ENTER;
to change one of them, enter the line number:  <ENTER>



*** PROGRAM TRENDS OUTPUT ***

Model of change: EXPONENTIAL
Pattern of variance: CV PROPORTIONAL TO 1/SQRT(A)
Calculation based on Z distribution
Alpha =       .050 (2-tailed)
Rate  =      -.100
CV    =       .130
Sample size =    5

Given these parameters, power is estimated to be  .64

                        [Note  the  asymmetry  in  power  between
                        increasing and decreasing trends]
```

```
Do you wish to try another calculation? (Y/N)  n

Results for this run are stored in TRENDS.OUT.
                        [Exit TRENDS, return to system control]
```

For this example, the exponential model was chosen because the population was recovering from previous heavy exploitation. CV proportional to 1/sqrt(A) was chosen because the flights were strip transects (see Gerrodette 1987, Table 1). The z distribution was chosen for consistency with the results of the 1987 paper; more discussion of this choice follows with the deer example.

At the conclusion of the run, the file TRENDS.OUT contains the results of all calculations, and the file TRENDS.INP contains the input values for the last calculation. For the example run above, the input file would now be:

```
  5                  index of parameter to be computed
  5                  number of samples (n)
 -.100               rate of change (+/- r)
  .130               initial coeff. of variation (CV1)
  .050               significance level (alpha)
  (to be computed)   power (1-beta)
 -2                  1- or 2-tailed test
  2                  model (1=linear, 2=exponential)
  1                  pattern of CV with abundance A
  1                  distribution index (1=z, 2=t)
```

Notice that the first record indicates the parameter to be computed, but this is not displayed on the screen. The input file can be edited directly with any ASCII editor, but this is not recommended because it will bypass error checks within the program.

The sign of line 2 (rate of change) and line 6 (1- or 2-tailed test) should always be the same; the program will enforce this. The reason for using a sign on line 6 occurs when r is the parameter to be estimated. The user indicates whether the positive or negative solution for r is desired by the sign given on line 6. Solutions for increasing and decreasing trends will generally be different, as the example run shows.

The results are to be interpreted as follows:

If the parameter to be computed is	the answer means that
n	n is the minimum number of sampling occasions that are needed at the given error rates; the number of sampling intervals is n-1.
r	r is the minimum rate of change (per sampling interval) that can be detected at the given error rates.
CV1	CV1 is the maximum permitted CV (minimum required precision) for the initial sample at the given error rates; CVs change with samples according to the pattern specified on line 8.
α	α is the probability of obtaining a significant trend (slope 0) falsely (Type 1 error).
power	power is the probability of obtaining a significant trend (slope 0) correctly (= 1-β, where β is the probability of Type 2 error).

<u>White-tailed deer</u>

Storm et al. (1992) reported a comparison of 2 techniques for estimating deer density near Gettysburg National Military Park. This example is based on the data presented in their Table 2 for the November population estimates, summarized below:

	Mark-resight			Area-conversion		
Year	Est.	SE	CV	Est.	SE	CV
1987	983	26.8	0.027	692	91.3	0.132
1988	1220	99.2	0.081	850	88.4	0.104
1989	1647	191.5	0.116	1164	180.4	0.155
1990	1592	136.5	0.086	1013	53.8	0.053
Mean			0.078			0.111

These data are used with TRENDS to obtain approximate answers to the following questions:

(1) If the deer population is monitored for 5 years, what is the probability of being able to detect a 10%/year growth in population size?

(2) If the deer population is monitored for 5 years, what is the minimum rate of population growth that we can expect to be able to detect with 90% probability?

(3) How many years must the population be monitored to be able to detect 10%/year rate of population growth with 95% probability?

To answer these questions, we must make some choices about the different options that TRENDS offers. Let us assume a significance level (α) of 0.05, a 2-tailed test, and an exponential model of growth. From the table above, it is obvious for the mark-resight method that CV increases with abundance, so we choose the option

"CV proportional to sqrt(A)." Notice that this choice is also expected on theoretical grounds for mark-recapture-type population estimates (Gerrodette 1987, Table 1). For the area-conversion method, plotting CV against sqrt(A) or 1/sqrt(A) shows no clear relationship; we therefore choose the middle option "CV constant with A."

We also need to estimate the initial coefficient of variation CV1. TRENDS uses the CV computed on the untransformed data. One method is simply to average the annual CVs, giving 0.078 and 0.111 for the mark-resight and area-conversion methods, respectively. However, these are probably underestimates of the residual variance we can expect in future surveys for the following reasons.

First, CV1 is the coefficient of variation at the <u>beginning</u> of the monitoring period. As abundance changes, CV will also change, as shown above for the mark-resight estimates. If monitoring will begin in 1991, a CV estimated from the most recent years will be better than an average of all years. An improved estimate for the mark-resight method, therefore, would be CV1 = (.116+.086)/2 = 0.101. CV for the area-conversion method does not seem to be related to abundance, so the average CV of all years is retained.

Second, averaging the annual CVs does not account for additional residual variance about the regression line that will occur because of variation in r. Several reviewers have pointed out this problem; it is also discussed in Gerrodette (1987). Even if population size were known exactly each year (no estimation error), the points would not lie precisely on the regression line, but would deviate from it due to various stochastic factors. If we are so fortunate as to have data from past surveys, as in the present example, the additional variation can be estimated by regression. On untransformed mark-resight data, regression of population estimate on year gives an estimate of CV1 = root mean square error / mean y = 148/1361 = 0.109; alternately, on log-transformed mark-resight data, CV1 = root mean square error = 0.110. These answers are nearly identical. Note that the RMSE of the log-linear regression is used directly as an estimate of the untransformed CV. For the area-conversion method estimates, similar calculations give CV1 = 0.158 and CV1 = 0.151 for untransformed and log-transformed regressions, respectively. The estimates of CV1 from the log-transformed regressions, namely, 0.110 for the mark-resight and 0.151 for the area-conversion, will be used in this example.

TRENDS also asks the user to choose either the standard normal (z) or Student's (t) distribution as the basis of calculation. In general, the t distribution should be used. Consider whether, on each sampling occasion, the method of estimation or measurement produces a single estimate of A, or whether an estimate of var(A) is also produced. The rationale for using the z distribution is to take advantage of the extra information present when an estimate of var(A) is available. Calculations based on the z distribution, however, make stronger assumptions and give more optimistic answers. Refer to Link and Hatfield (1990) and Gerrodette (1991) for further discussion. If in doubt, use the more conservative t distribution.

With these choices made, the input file to answer question #1 for the mark-resight method is

```
5                  index of parameter to be computed
5                  number of samples (n)
.100               rate of change (+/- r)
.110               initial coeff. of variation (CV1)
.050               significance level (alpha)
(to be computed)   power (1-beta)
2                  1- or 2-tailed test
2                  model (1=linear, 2=exponential)
3                  pattern of CV with abundance A
2                  distribution index (1=z, 2=t)
```

which gives an estimated probability of detection (power) of 0.41. For the area-conversion method, the input file is

```
5                  index of parameter to be computed
5                  number of samples (n)
.100               rate of change (+/- r)
.151               initial coeff. of variation (CV1)
.050               significance level (alpha)
(to be computed)   power (1-beta)
2                  1- or 2-tailed test
2                  model (1=linear, 2=exponential)
2                  pattern of CV with abundance A
2                  distribution index (1=z, 2=t)
```

which yields an estimated probability of detection of 0.29.

Proceeding in a similar way for question #2, we find the estimated minimum detectable rate of growth (r) to be 0.25 for the mark-resight method and 0.27 for the area-conversion method. For question #3, TRENDS estimates that a minimum of 8 years (actually, 8 surveys over 7 year-long intervals) will be required with either method to detect the growth in population size.

Despite the greater precision of the mark-resight method, these calculations indicate little difference among the 2 techniques for detecting trends in white-tailed deer herd size.

The main reason for this is the assumed pattern of CV with abundance: the mark-resight method becomes less precise as population increases, so it is less able to detect a trend. This illustrates that the choice of change in CV with abundance can be important. If herd size were declining, however, the mark-resight method would become more precise and perform better relative to the area-conversion method.

It is usually surprising and sometimes depressing to find out how low power is, how high the detectable rate of change is, and how many years are required to detect a change. Although the answers given by TRENDS are approximations, they nevertheless indicate that we often tend to be overly optimistic about how likely our surveys are to detect changes in population size.

It cannot be emphasized too strongly that the answers provided by TRENDS are approximate. This results from several factors:

(1) Calculations are dependent on choosing the right model. TRENDS assumes we have selected the linear regression model to represent our system, but we should never forget that any model is an approximation of biological reality. It is surely an oversimplification, for example, to assume that population size will change in an exactly regular manner over a period of time, but that is the fundamental assumption of a linear regression on a time series of population estimates.

(2) Calculations are conditional on values of parameters not known in advance. Our statements are of the form "_If_ the population grows at 10%/year for the next 5 years, the probability

of detecting this growth is 0.41." But if it turns out that the population grew at 15%/year, the probability of detection will be quite different. Estimating a CV that reflects all sources of variation is particularly important because the power calculations are sensitive to this parameter.

(3) Calculations are based on the same assumptions as linear regression - normal error distributions, equal variances, and independence of estimates. Often we do not know if these assumptions are true. Violations of these assumptions make the results of TRENDS (and the linear regression itself) approximate.

(4) Calculations are based on some numerical approximations even if these assumptions are satisfied (see the technical discussions in Link and Hatfield 1990 and Gerrodette 1991).

Nevertheless, answers provided by TRENDS (or a similar power analysis) will be useful in (1) assessing whether a proposed design has even a reasonable chance of detecting a trend, (2) estimating the number of sample occasions that will be required, (3) providing an estimate of the rate of change that will be detectable, and (4) comparing the efficacy of different proposed survey designs.

ERROR CONDITIONS AND POSSIBLE PROBLEMS

Program TRENDS will calculate an answer for reasonable values of the parameters, but it is impossible to anticipate all possible situations. For some combinations of parameters, no numerical solution is possible. For others, particularly very large or very small values of the parameters, underflow, overflow, or other numerical problems may occur. These will be indicated by run-time error messages. In this case, try less extreme values. The program also has a number of error traps. Most impermissible values will be caught on input, but if not, they may be detected by subroutine TREND, which returns the following error codes:

IER	Error condition
1	wrong parameter chosen (must be 1-5)
2	number of samples (n) too small
3	rate of change (r) = 0
4	initial CV # 0
5	α # 0 or ∃ 1
6	power # 0 or ∃ 1
7	tails for test 1 and 2
8	model of change 1 and 2
9	change of CV with A < 1 or > 3
10	choice of z or t distribution 1 and 2
11	wrong tail of distribution (r and ITAIL have opposite signs)
12	root not bracketed, hence not found

If the program is used for input, the first 11 errors should not occur. Attempts to input values out of range will trigger error messages and the user will be prompted for a new value. If input file TRENDS.INP is edited directly, no checking occurs until subroutine TREND is called, so any of these messages may appear. IER = 12 means that the program was unable to solve for a root. The combination of input values either does not permit a solution, or is so close to one of the boundary conditions that problems were encountered. Try again with less extreme values.

Careful readers may note small numerical differences between the results of TRENDS and some graphs and tables in Gerrodette (1987) and Holt et al. (1987). These are due to improvements to the code and the correction of one bug. The bug affected the calculations of power for small effects in the 2-tailed case. Note the different y-intercepts of the 1- and 2-tailed curves in Fig. 3 of Gerrodette (1987). These should be the same, and equal to the Type 1 error rate (0.05 in this case). The current program has corrected this bug.

Problems encountered when using this program should be reported to the author, together with the input file used.

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